CRC-274

AN AIR COMBAT MANEUVER CONVERSION MODEL

CENTER FOR NAVAL ANALYSES
1401 Wilson Boulevard
Arlington, Virginia 22209

Operations Evaluation Group

BY: RICHARD A. OBERLE

7

November 1974

Approved for public release; distribution unlimited.

Prepared for:

OFFICE OF NAVAL RESEARCH
Department of the Navy
Washington, D.C. 20350

OFFICE OF THE CHIEF OF NAVAL OPERATIONS (Op03)
Department of the Navy
Washington, D.C. 20380

02 027400.00

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER CRC 274	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) An Air Combat Maneuver Conversion Model		5. TYPE OF REPORT & PERIOD COVERED 6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) Richard A. Oberle		8. CONTRACT OR GRANT NUMBER(s) N00014-68-A-0091
9. PERFORMING ORGANIZATION NAME AND ADDRESS Center for Naval Analyses 1401 Wilson Boulevard Arlington, Virginia 22209		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
11. CONTROLLING OFFICE NAME AND ADDRESS Office of Naval Research Department of the Navy Washington, D.C. 20350		12. REPORT DATE November 1974 13. NUMBER OF PAGES 25
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office) Office of the Chief of Naval Operations (Op03) Department of the Navy Washington, D.C. 20380		15. SECURITY CLASS. (of this report) Unclassified 15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

This Research Contribution does not necessarily represent the opinion of the Department of the Navy.

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

aerial warfare, maneuverability, Markov processes, mathematical models, simulation, statistical processes

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

A model that characterizes an air-to-air engagement as a semi-Markov process is described. Included is a discussion of the model's assumptions and effectiveness measures with instructions for applying the model to experiments characterizing offensive and defensive maneuvering capability in air combat.

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE
S/N 0102-014-6601

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

Center for Naval Analyses

1401 Wilson Boulevard Arlington, Virginia 22209 703/524-9400

An Equal Opportunity Employer

an affiliate of the University of Rochester

21 May 1975

MEMORANDUM FOR DISTRIBUTION LIST

Subj: Center for Naval Analyses Research Contribution 274

Encl: (1) CRC 274, "An Air Combat Maneuver Conversion Model," Richard A. Oberle, November 1974

1. Enclosure (1) is forwarded as a matter of possible interest.

2. This Research Contribution describes a model that was designed for use in the evaluation of test range air combat maneuvering engagements. The model appears to have applications for the measurement of aircraft and weapon system performance, as well as the evaluation of aircrew proficiency and the selection of threat simulation aircraft.

3. Research Contributions are distributed for their potential value in other studies and analyses. They do not necessarily represent the opinion of the Department of the Navy.

4. The enclosure is approved for public release.

Phil E. DePoy

PHIL E. DePOY
Director
Operations Evaluation Group

Distribution List:
Reverse page

DISTRIBUTION LIST

Department of the Navy

SNDL Part 1:

21A	CINCPACFLT, CINCLANTFLT, CINCUSNAVEUR
22	COMSECONDFLT, COMTHIRDFLT, COMSIXTHFLT, COMSEVENTHFLT
24A	COMNAVAIRPAC, COMNAVAIRLANT
26F	COMOPTEVFOR, DEPCOMOPTEVFORPAC
28A	COMCARGRU 1, 2, 3, 4, 5, 6, and 7
42L1	FITWING 1; FITRONs; FITRON 101, Det Key West; FITWEPSCOL
42S	VX-4, VX-5

SNDL Part II:

A2A	OPA
A4A	CHNAVMAT
FKA1A	NAVAIRSYSCOMHQ
FKA6A1	NAVAIRDEVCEN
FKA6A2	NAVWPNCEN
FKR3C	NAVAIRTESTCEN
FKR5	NAVAVIONICFAC
FT1	CNET
FT2	CNATRA
FT10	NAVAVSCOLSCOM
FT13	NATTC (Lakehurst, NJ and Millington, TN)
FT69	USNA ANNA
FT73	NAVPGSCOL
FT75	NAVWARCOL

OpNav: Op-09BH, Op-96, Op-099, Op-03, Op-05

Other

Senior Naval Member, Weapon Systems Evaluation Group
Defense Documentation Center (12 copies)
Department of the Air Force (AFXODL)(9 copies)
Air Force Test & Evaluation Center, Albuquerque, NM
Aerospace Corporation
Institute for Defense Analyses
The Rand Corporation
University of Rochester (2 copies)

TABLE OF CONTENTS

INTRODUCTION

This research contribution describes a model for evaluating one-on-one and two-on-one ACM (air combat maneuvering) engagements. The model basically consists of structuring an air-to-air engagement into a semi-Markov process with two potentially absorbing states.

The model allows estimating a family of engagement statistics. These consist of the Markov statistics and tactical measures that are peculiar to ACM engagements and that characterize ACM performance for typical engagements between combatants from two classes: an evaluation class (friendly forces) and an opposition class (enemy forces). The definitions of the combatant classes enable interpreting the engagement statistics as a numerical measure of pilot, aircraft model, weapon system, mission goal, and tactics interaction in one-on-one and two-on-one ACM engagements. This, in turn, enables the analyst to identify the relative ACM capability of the combatant classes and predict the outcome of a representative engagement.

BACKGROUND

Development of the model was motivated by the lack of a systematic technique for evaluating flight test data. Historically, evaluation of ACM flight test engagements has consisted of a reporting of average time in weapon envelope and average weapon opportunities per engagement, combined with pilot opinion of ACM potential.

The assumptions and conventions of the model described here isolate measures of effectiveness (MOEs) for ACM engagements and standardize interpretation of the engagement statistics.

ONE-ON-ONE ACM PROBLEM

An aggressive air-to-air engagement between 2 aircraft is usually characterized by sequences of offensive and defensive maneuvers designed either to gain an advantage or to negate an opponent's advantage. Offensive maneuvering is used to gain a position from which weapons may be used against the opponent. Defensive maneuvering is used not only to negate an opponent's offensive maneuvers or weapon opportunity, but also to raise the state of the engagement to near "even off" -- that is, a state where neither opponent has a significant tactical advantage.

ACM ENGAGEMENT DYNAMICS

The dynamics of an ACM engagement are usually described by the relative vector geometries and the altitudes and airspeeds of the combatants. Figure 1 defines the terms used in describing the relative vector geometry. Relative range is the separation of the aircraft considered as points in space. A fighter's "look" angle (sometimes called "angle off") is the angle in space determined by the intersection of the line of sight to the opponent and the fighter armament datum line, which is the aircraft's centerline extended into space.

Each combatant in a one-on-one engagement enters with one of two possible mission objectives. One is to negate the opponent's attack and survive the engagement; this could be the objective of an attack aircraft not armed for aggressive air-to-air combat. The other possible objective is aggressive air combat, as for a fighter aircraft armed with air-to-air ordnance to obtain and maintain complete control of some specified airspace.

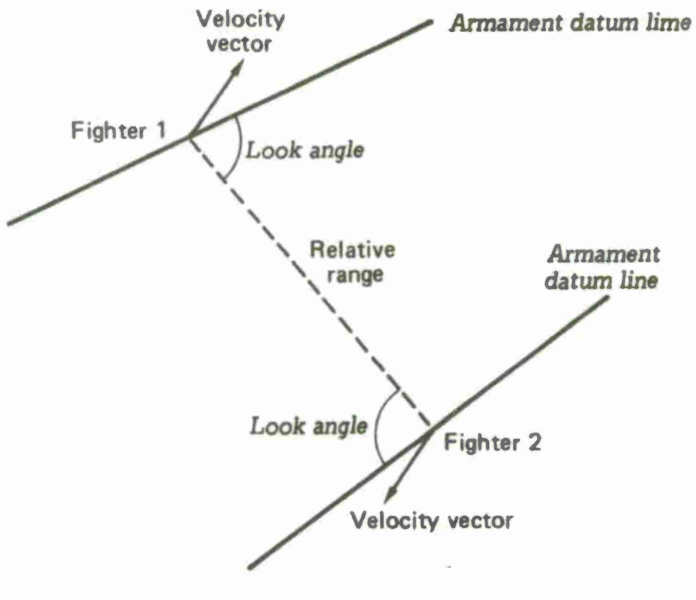

FIG. 1: DEFINITIONS OF ACM RELATIVE POSITION TERMS

The combatants may enter the engagement roughly even, with neither aircraft having a significant tactical advantage. Or, one of the combatants may have some tactical advantage. Two aircraft, armed with rear-hemisphere ordnance and passing head-on, for example, would constitute an engagement with even initial conditions. One combatant under ground-control intercept (GCI) and abeam of the other who is unaware of the situation and aided only by on-board sensors is an example of starting conditions where one combatant has a significant tactical advantage.

"Tactical advantage" is used here only in the sense of "spatial tactical advantage" -- that is, a significant positional advantage (defined in terms of angles off and relative ranges); a weapons opportunity; or outside intelligence information.

DESCRIPTION OF THE MODEL

DEFINITION OF TERMS

Consider two classes of combatants, C and $\tilde{C}$, each consisting of a well-defined collection of pilots, specific aircraft type, fixed weapon load, and specific mission goal. Class C is the evaluation (friendly) class, and $\tilde{C}$ is the opposition (enemy) class. Examples of combatant classes are:

- All enemy pilots in a particular threat aircraft with a standard weapon load and aggressive ACM mission.

- All NFWS (Navy Fighter Weapons School) instructors in A-4 aircraft armed with AIM-9D missiles and on an aggressive ACM mission.

- F-4 RAG (replacement air group) instructors or students in F-4 aircraft armed with AIM-7/AIM-9 missiles and on an aggressive ACM mission.

- A particular pilot with a specific aircraft, weapon load, and mission.

- Any of the above with the additional restriction that the participating pilots use only a predefined family of offensive and defensive maneuvers during representative engagements.

When a family of available tactics is not specified in the definition of the combat classes, it is assumed that the engaging aircrews are using tactics recommended in the tactics manual for the test's operational conditions.

A representative one-on-one ACM engagement is one between an element $c \in C$[1] and $\tilde{c} \in \tilde{C}$. C and $\tilde{C}$, the classes of combatants, are the basic tactical entities to be compared by the model. The model statistics are to be interpreted as determining the expected trend of a representative engagement between these two classes. The selection of the classes is completely up to the analyst; the only restriction is in interpreting the representative engagement statistics.

ASSUMPTIONS

The assumptions used in constructing the model of a one-on-one engagement between a fighter and an opponent are:

- At any time during the engagement, the relative vector dynamics of the combatants may be characterized by five engagement state categories -- offensive weapon, offensive, neutral, defensive, and fatal defensive (see table 1).

---

[1] Read "c is an element of C."

- The probability of a transition from one state to another by either combatant is dependent only on the current state and independent of all prior states.

- At least one combatant is limited to rear-hemisphere weapons.

The first assumption simplifies all possible relative geometries/dynamics into a few tactical classifications. Other than requiring that engagement state classifications be complimentary -- that is, one combatant is offensive (O) or offensive weapon (OW) when and only when the other combatant is, respectively, defensive (D) or fatal defensive (FD) -- there are no restrictions on the dynamic criteria that may be used in defining state. For example, offensive state may be defined solely in terms of a positional advantage and a positive energy differential. Although the actual dynamics of an ACM engagement can result in a rapid, almost instantaneous succession of state conversions, the model restricts state conversion to the adjacent state. Table 2 gives state conversion possibilities.

The second assumption is based on observations of ACM engagements conducted on instrumented test ranges; it results in simplified MOEs. The third assumption is covered in the next section.

LIMITATIONS

The requirement that the state conditions be complementary limits the type of weapon load combinations that may be analyzed. Specifically, the model applies to one-on-one engagements in which at least one combatant is limited to rear-hemisphere weapons. For example, an engagement between an F-4 armed with AIM-7E-2, AIM-9D, and guns and an A-4 armed with AIM-9D and guns may be evaluated by the model. But an engagement between 2 F-4s, each armed with AIM-7E-2 (and possibly other weapon systems), cannot

TABLE 1

ENGAGEMENT STATE CATEGORIES
(Relative to the Evaluation Fighter)

Offensive weapon (OW): Evaluation fighter has a weapons opportunity.

Offensive (O): Evaluation fighter has a significant tactical advantage.

Neutral (N): No combatant has a significant tactical advantage or disadvantage.

Defensive (D): Opponent has a significant tactical advantage.

Fatal defensive (FD): Opponent has a weapon opportunity.

be evaluated since both can have a weapon opportunity simultaneously. For instance, the 2 F-4s can close head-on, both having an AIM-7E-2 opportunity; the analysis of such engagements requires a model with additional state conditions.

TABLE 2

STATE CONVERSION POSSIBILITIES

Current engagement state	Kill	Offensive weapon	Offensive	Neutral	Defensive	Fatal defensive	Loss
Offensive weapon	*	-	*	-	-	-	-
Offensive	-	*	-	*	-	-	-
Neutral	-	-	*	-	*	-	-
Defensive	-	-	-	*	-	*	-
Fatal defensive	-	-	-	-	*	-	*

(*) = Permissible state change.
(-) = Not permissible state change.

MEASURES OF EFFECTIVENESS

The MOEs used within the model to characterize the relative ACM ability of two combatant classes are divided into three categories. The first category -- the semi-Markov statistics -- completely characterizes a representative engagement as a semi-Markov process. That is, the semi-Markov statistics completely determine the distribution of engagement states as engagement time accumulates. The second category -- weapon employment effectiveness measures -- quantifies the absorbing effect of the two boundary states, offensive weapon and fatal defensive. The third category -- tactical measures -- quantifies fighter aggression as well as offensive and defensive maneuvering capability.

Semi-Markov Measures

- Engagement state conversion probabilities: for each engagement state, the two complementary probabilities, each of which weights the likelihood of a conversion to an adjacent state.

- Time-in-state distribution: for each engagement state, the frequency function defining the time in state -- that is, the frequency function defining the time from entry into the state to transition to an adjacent state.

Weapon Employment Effectiveness

- Weapon opportunity recognition: probability that the pilot will recognize a weapon opportunity and expend ordnance.

- Weapon waste rate: probability that a pilot will misjudge a tactical advantage for a weapon opportunity and erroneously expend ordnance out of envelope.

Tactical Measures

- Fighter capability index (FCI): probability of achieving the first weapon opportunity in the engagement.

- First firing probability (FFP): probability of obtaining and exploiting the first weapon opportunity in the engagement by expending ordnance.

- Engagement domination index (EDI): expected fraction of engagement time in offensive or offensive weapon state.

- Engagement survivability index (ESI): expected fraction of engagement time in neutral or higher state.

- Exchange ratio: ratio of the probability of a kill to the probability of a loss on a representative engagement.

The family of state-conversion probabilities and the frequency functions (table 3) giving time in state completely determine the distribution of engagement states as engagement time accumulates. The weapon-opportunity-recognition and weapon-waste rates measure the proficiency of aircrew weapon employment (or weapon system); consequently, they may be used to identify training requirements or weapon system computational deficiencies. The fighter-capability index measures aggressive maneuverability, and the first-firing probability (the product of the fighter-capability index and the weapon-opportunity-recognition probability) is a measure of combined aggressive maneuvering and weapon-employment effectiveness.

The engagement domination index measures the amount of engagement control by quantifying the ability to keep the opponent maneuvering defensively. The engagement survivability index, by contrast, measures the ability to avoid defensive maneuvering, thus negating the opponent's aggression. While not directly predicting the engagement's outcome, these two indexes identify general offensive and defensive maneuvering ability.

TABLE 3

ACM CONVERSION MATRIX

Engagement state	Possible state change	State change (transition) probability	Time in state probability distribution[a]
Offensive weapon	Kill	p_k[b]	F(OW, ·)
	Offensive	$1 - p_k$	
Offensive	Offensive weapon	p(O, OW)	F(O, ·)
	Neutral	p(O, N)	
Neutral	Offensive	p(N, O)	F (N, ·)
	Defensive	p(N, D)	
Defensive	Neutral	p (D, N)	F(D, ·)
	Fatal defensive	p(D, FD)	
Fatal defensive	Defensive	$(1 - p_l)$	F(FD, ·)
	Loss	p_l[b]	

[a] For each engagement state S, the symbol F(S, ·) represents the distribution function characterizing time in state S before transition to an adjacent state.

[b] p_k is the probability of kill given a launch opportunity and weapon expenditure by the evaluation fighter. It is the product of the probability of weapon opportunity recognition and employed-weapon effectiveness. The employed-weapon effectiveness is the probability of kill given a launch within envelope

p_l is defined analogously.

The indexes FCI, FFP, EDI, and ESI (see the section on tactical measures) depend on the initial engagement conditions. The exchange ratio is a fleet-level effectiveness measure that may be used to evaluate relative effectiveness in wartime scenarios. A detailed analytical treatment will be published separately with the intent of deriving average exchange ratios and other effectiveness estimates by semi-Markov and Monte Carlo methods.

ESTIMATING ENGAGEMENT PARAMETERS

The evaluation class C or the opposition class $\tilde{C}$ consists of a well-defined family of pilots P ($\tilde{P}$); a specific aircraft type A/C ($\widetilde{A/C}$); a weapon system W/S ($\widetilde{W/S}$), including the type of armament and the weapon control system; and a family of specified tactics T ($\tilde{T}$). The abstract class may thus be denoted $C = (P, A/C, W/S, T)$ and a representative element $c = (p, A/C, W/S, T)$ for $p \epsilon P$.

Let $p_1, \ldots, p_n \epsilon P$ and $\tilde{p}_1, \tilde{p}_2, \ldots \tilde{p}_n \epsilon \tilde{P}$ be random samples of size n from the appropriate family of pilots. The family of n^2 engagements of c_i vs. $\tilde{c}_j$ for i, j=1, 2, ..., n, with $c_t = (p_t, A/C, W/S, T)$ $\tilde{c}_t = (\tilde{p}_t, \widetilde{A/C}, \widetilde{W/S}, \tilde{T})$ for $t = 1, 2, \ldots, n$, is called the standard experiment of size n. Table 4 shows the matrix representing this experiment. The matrix entries are used to define the relative state of the combatants at the start of the engagement -- that is, initial relative position, altitude, and airspeed.

Estimation of the engagement parameters from a sample of engagements between classes C and $\tilde{C}$ requires that each engagement in the standard experiment be summarized as in figure 2. The form provides a complete summary of the engagement state conversions, state time distribution, and weapon opportunities/firings necessary for calculating the model statistics. Assessment of engagement state condition requires range-tracking data describing the engagement dynamics. Pilot voice tape correlated with range engagement time are sufficient for isolating firing incidents. The model statistics to be calculated from the engagement samples are in table 5.

When the experiment is intended to measure the relative ACM capabilities of the two classes, the initial conditions should be uniformly distributed among the five engagement states. This is done by properly distributing the initial relative vector dynamics.

This general approach may be modified to accommodate specific questions in specialized test plans. For example, if the evaluation team were interested only in the defensive capability of the evaluation class, each engagement would begin with the evaluation fighter in defensive state. This would ensure a large sample, thus increasing confidence in the numerical estimate of the conversion probabilities from the defensive to adjacent states.

Since airframe performance varies with altitude and airspeed, the analyst must ensure that the experiment is controlled so it samples ACM performance in a specific altitude/airspeed arena consistent with the capability in question. This can be done by restricting either the start condition or the family of engagement tactics. For example, when the analyst is interested in examining the ACM capability of the evaluation class at slow-speed, medium-altitude engagement, all engagements could be so started. When this is tactically unrealistic, the engagements could be started in a tactically more appropriate arena, with one or the other of the combatants required to draw the engagement into a slow-speed duel.

TABLE 4

ENGAGEMENT MATRIX FOR THE STANDARD EXPERIMENT

Representative pilot sample (Opposition class)

Representative pilot sample (Evaluation class)	$\tilde{p}_1$	$\tilde{p}_2$	$\tilde{p}_3$	$\cdots$	$\cdots$	$\cdots$	$\tilde{p}_n$
p_1	*	*	*	$\cdots$	$\cdots$	$\cdots$	*
p_2	*	*	*	$\cdots$	$\cdots$	$\cdots$	*
p_3	*	*	*	$\cdots$	$\cdots$	$\cdots$	*
$\cdots$	$\cdots$	$\cdots$	$\cdots$				
	$\cdots$	$\cdots$	$\cdots$				
p_n	*	*	*	$\cdots$	$\cdots$	$\cdots$	*

* Matrix entry defines the engagement's initial conditions -- relative position, altitude, and airspeed.

Description of combatant classes

	Evaluation class	Opposition class
Pilot classification	P	$\tilde{P}$
Aircraft (model/configuration)	A/C	$\widetilde{A/C}$
Weapon system	W/S	$\widetilde{W/S}$
Tactics	T	$\tilde{T}$

DATE: ____________________ OP. NO./RUN ____________________

I. *DEFINITION OF COMBATANT CLASSES*

	FIGHTER 1	FIGHTER 2
AIRCRAFT TYPE		
WEAPON LOAD		
CREW		
MISSION CODE		
ENGAGEMENT TACTICS RESTRICTIONS		

II. *TACTICAL ENGAGEMENT SUMMARY*

INITIAL SETUP (Including Altitude/Airspeed) ____________________

TIME	ENGAGEMENT STATE	REMARKS AND FIRING INDICATIONS

III. *ENGAGEMENT EVALUATION*

A. STATE CONVERSION SUMMARY

CONVERSION OPTION	NUMBER OF CONVERSIONS	CONVERSION OPTION	NUMBER OF CONVERSIONS
OFF WPN TO OFF		OFF TO OFF WPN	
OFF TO NEUTRAL		NEUTRAL TO OFF	
NEUTRAL TO DEF		DEF TO NEUTRAL	
DEF TO FATAL DEF		FATAL DEF TO DEF	

B. TIME IN ENGAGEMENT STATE

STATE	NUMBER OF TIMES IN STATE	DURATIONS *(List sequentially)*	TOTAL TIME
OFFENSIVE WEAPON			
OFFENSIVE			
NEUTRAL			
DEFENSIVE			
FATAL DEFENSIVE			

C. WEAPON EXPENDITURE SUMMARY

	FIGHTER 1 WEAPON TYPE				FIGHTER 2 WEAPON TYPE			
	1	2	3	4	1	2	3	4
OPPORTUNITIES								
VALID FIRINGS								
INVALID (OUT-OF-ENVELOPE) FIRINGS								

FIG. 2: ONE-ON-ONE ENGAGEMENT RECONSTRUCTION AND EVALUATION FORM

DATE: Enter calendar date of operation.

OP NO./RUN: Enter operation number and engagement number.

A/C TYPE: Enter aircraft type and model.

WEAPON LOAD: Enter number and type of each on-board air-to-air weapon.

CREW: Enter crew names or serial numbers.

MISSION CODE: Enter 1 for aggressive air combat, 2 for defensive, survival maneuvering.

INITIAL TACTICAL SETUP: Enter the relative tactical position, altitude, and airspeed of the engaging aircraft.

TIME/STATE SUMMARY: Starting at time t = 0, enter the initial engagement state. At each state conversion, enter the time of conversion and the new engagement state. Include firing indications in the "remark" column with appropriate time indication.

STATE CONVERSION SUMMARY: For each conversion option (neutral to defensive, neutral to offensive, etc.), enter the number of observed engagement conversions.

TIME IN ENGAGEMENT STATES: For each engagement state, enter the number of times in that state and list the times in state sequentially in the "duration" column.

WEAPON EXPENDITURE SUMMARY: For each fighter and each weapon type, enter the number of weapon opportunities, the number of valid (in-envelope) firings, and the number of invalid (out-of-envelope) firings.

FIGURE 2 (Continued)

TABLE 5

CUMULATIVE PERFORMANCE PARAMETERS FOR ESTIMATING SUMMARY STATISTICS

$p(X - 1, X) = \dfrac{\text{Number of conversions from } (X - 1) \text{ status to } (X) \text{ status}}{\text{Number of times in } (X - 1) \text{ status}}$

$p(X, X - 1) = \dfrac{\text{Number of losses of X status to } (X - 1) \text{ status}}{\text{Number of times in } (X) \text{ status}}$

$F(X, \cdot)$ = Empirical distribution describing time in state X

p_{WOR} = Ratio of the number on in-envelope firings to the total number of firing opportunities

p_{FF} = Ratio of the number of engagements within envelope firing before the enemy makes an in-envelope firing to the number of engagements

WWR = Ratio of the total number of invalid firings to the total number of engagements

EDI = Fraction of the total engagement time spent in offensive or defensive weapon state

ESI = Fraction of total engagement time spent in neutral or higher state.

FCI = Fraction of the engagements in which the evaluation fighter is the first combatant to obtain a weapon opportunity

Legend:

1. X — Fatal defensive, defensive, neutral,, offensive, offensive weapon
2. p_{WOR} — Probability of weapon-opportunity recognition
3. p_{FF} — Probability of first firing in the engagement
4. EDI — Engagement domination index
5. ESI — Engagement survivability index
6. FCI — Fighter capability index

ANALYSIS OF TWO-ON-ONE ENGAGEMENTS

The objective of a two-on-one engagement is to convert numerical superiority to a tactical advantage without losing section integrity. In other words, the combatants in the fighter section must be tactically supporting each other throughout the engagement. The evaluation of a section as an ACM unit is complicated by the fact that one of the section fighters can be in a defensive state; but the section as a whole may actually be on offense.

Table 6 gives a set of criteria that may be applied to a two-on-one engagement. Since the two-on-one evaluation uses the methods applied to one-on-one engagements, it is subject to the limitation that either both aircraft in a section or the opponent is restricted to rear-hemisphere weapons. For example, an engagement between 2 A-4s armed with AIM-9D and guns and an F-4 armed with AIM-7E-2, AIM-9D, and guns may be evaluated. Figure 3 shows an engagement summary form modified to fit two-on-one engagements. The basic engagement statistics summary/presentation format is unchanged from the one used for one-on-one engagements.

TABLE 6

RULES FOR STATE EVALUATION OF A TWO-ON-ONE ENGAGEMENT

1. The section is offensive weapon when at least one member is in offensive weapon state and the other is higher than a fatal defensive state.
2. The section is offensive when at least one member has an offensive position and the other is higher than a fatal defensive state.
3. The section is neutral when both members are in neutral state.
4. The section is defensive when at least one member is in defensive state and the other is either neutral or defensive.
5. The section is fatal defensive when at least one member is in fatal defensive state and the other has less than offensive weapon state.
6. The section is in a tradeoff state when one member of the section is in offensive weapon state and the other is in a fatal defensive state.

DATE: ____________________ OP. NO./RUN ____________________

I. *DEFINITION OF COMBATANT CLASSES*

	SECTION FIGHTER 1	SECTION FIGHTER 2	SECTION OPPONENT
AIRCRAFT TYPE			
WEAPON LOAD			
CREW			
MISSION CODE			
ENGAGEMENT TACTICS RESTRICTIONS			

II. *TACTICAL ENGAGEMENT SUMMARY*

INITIAL SETUP ____________________

ENGAGEMENT TIME	SECTION STATE	REMARKS AND FIRING INDICATIONS

III. *ENGAGEMENT EVALUATION*

A. SECTION STATE CONVERSION SUMMARY

CONVERSION OPTION	NUMBER OF CONVERSIONS	CONVERSION OPTION	NUMBER OF CONVERSIONS
OFF WPN TO OFF		OFF TOO OFF WPN	
OFF TO NEUTRAL		NEUTRAL TO OFF	
NEUTRAL TO DEF		DEF TO NEUTRAL	
DEF TO FATAL DEF		FATAL DEF TO DEF	
ANY STATE TO TRADEOFF		TRADEOFF TO ANY STATE	

B. TIME IN ENGAGEMENT STATE

SECTION STATE	NUMBER OF TIMES IN STATE	DURATIONS *(List sequentially)*	TOTAL TIME
OFFENSIVE WEAPON			
OFFENSIVE			
NEUTRAL			
DEFENSIVE			
FATAL DEFENSIVE			
TRADEOFF			

C. WEAPON EXPENDITURE SUMMARY SUMMARY SECTION

	FIGHTER SECTION WEAPON TYPE				OPPOSITION FIGHTER WEAPON TYPE			
	1	2	3	4	1	2	3	4
OPPORTUNITIES								
VALID FIRINGS								
INVALID (OUT-OF-ENVELOPE) FIRINGS								

Instructions for recording data on this form are the same as those for figure 2, except that the evaluation of engagement state is relative to the section.

FIG. 3: TWO-ON-ONE ENGAGEMENT RECONSTRUCTION AND EVALUATION FORM

APPLICATIONS

FIGHTER SYSTEM FLYOFF

Consider the problem of selecting the best of 2 aircraft, A and B, in close ACM. Assume that each aircraft has a specific weapon system and a family of recommended tactics, such as detailed in the appropriate tactical manual. Aircraft A, for example, might be a low-performance airframe armed with a sophisticated weapon system; aircraft B might be a high-performance airframe with a less-sophisticated weapon system. The relative ACM potential of the aircraft may be measured by using the ACM conversion model to evaluate demonstrated flight performance in the standard experiment.

Except for an element-by-element comparison, multielement vectors of model performance statistics cannot be directly compared. However, with simulation, the exchange ratio for the aircraft being compared can be calculated.

Table 7 shows a general test matrix. For this experiment, only engagements starting even (neutral) need be evaluated. The pilot sample could be chosen from instructors at the Navy Fighter Weapons School. Since the evaluation is restricted to pure aircraft/weapon-system performance, a single sample of expert pilots should be used for both aircraft. If each pilot were given the opportunity to become ACM familiar in each aircraft, this procedure would eliminate a test bias attributable to differences in ACM capability for two different pilot classifications.

WEAPON SYSTEM FLYOFF

Consider 2 candidate weapon systems, A and B, being considered for mating with a specific aircraft. When it is not possible to make the selection on the basis of measured reliability or design capabilities of the 2 systems, the ACM conversion model offers the decision methodology for quantitatively evaluating a controlled flyoff. For this experiment, the evaluation class and the opposition class are identical except for the candidate weapon systems and tactics peculiar to their use. The test matrix is shown in table 8.

For this experiment, it is appropriate to begin each engagement in neutral state and compare weapon opportunities and fighter capabilitiy indexes for the ACM units. To eliminate any bias associated with pilot ability, the same sample of expert pilots is given the opportunity to engage all other sample pilots in each aircraft configuration (see table 9).

TABLE 7

FIGHTER SYSTEM FLYOFF ENGAGEMENT MATRIX

Representative expert pilot sample

Representative expert pilot sample	p_1	p_2	p_3	...	...	p_n
p_1	+	*	*			*
p_2	*	+	*			*
p_3	*	*	+			*
...						
...						
p_n	*	*	*			+

* Matrix entry defines the engagement's initial conditions -- relative position, altitude, and airspeed.

\+ Diagonal engagements are not possible when one pilot sample is used for the entire experiment.

Description of combatant classes

	Evaluation class	Opposition class
Pilot classification	P	P
Aircraft (model/configuration)	A	B
Weapon system	W/S (A)	W/S (B)
Tactics	T (A)	T (B)

TABLE 8

WEAPON SYSTEM FLYOFF ENGAGEMENT MATRIX

Representative pilot sample
(Opposition class)

Representative expert pilot sample
(Evaluation class)

	p_1	p_2	p_3	...	...	p_n
p_1	+	*	*			*
p_2	*	+	*			*
p_3	*	*	+			*
...						
...						
p_n	*	*	*			+

* Matrix entry defines the engagement's initial conditions -- relative position, altitude and airspeed.

\+ Diagonal engagements are not possible when one pilot sample is used for the entire experiment.

Definition of combatant classes

	Evaluation class	Opposition class
Pilot classification	P	P
Aircraft (model/configuration)	Test airframe	Test airframe
Weapon system	W/S (A)	W/S (B)
Tactics	T (A)	T (B)

TABLE 9

THREAT SIMULATION VALIDITY TEST

Representative expert pilot sample	p_1	p_2	p_3	...	...	p_n
p_1	+	*	*			*
p_2	*	+	*			*
p_3	*	+	+			*
...						
...						
p_n	*	*	*			+

* Matrix entry defines the engagement's initial condition -- relative position, altitude, and airspeed.

\+ Diagonal engagements are not possible when one pilot sample is used for the entire experiment.

Definition of combatant classes

	Evaluation class	Opposition class
Pilot classification	P	P
Aircraft (model/configuration)	Proposed simulator	Threat aircraft
Weapon system	W/S	W/S
Tactics	T	T

EVALUATION OF AIRCREW ACM PROFICIENCY IN FIGHTER WEAPONS SCHOOL

The ACM conversion model offers the Fighter Weapons School a method for grading the proficiency and improvement of students as they progress through the training syllabus and for assigning a final performance score at the completion of training. The appropriate evaluation class is comprised of the individual students (in an appropriate aircraft/weapon-system/tactics configuration) and the opposition class of instructors (in perhaps a different aircraft/weapon-system/tactics configuration).

The ACM performance parameters could be plotted as a function of student progress through the training syllabus, with the final value taken as the measure of current demonstrated ability. Figure 4 shows a representative plot. By noting areas where peak proficiency has been obtained or areas of weakness, training emphasis may be shifted to the weak areas so that overall student ACM ability is balanced. Implementation of such methodology to the evaluation of student performance will require some modification to the Fighter Weapon School training syllabus.

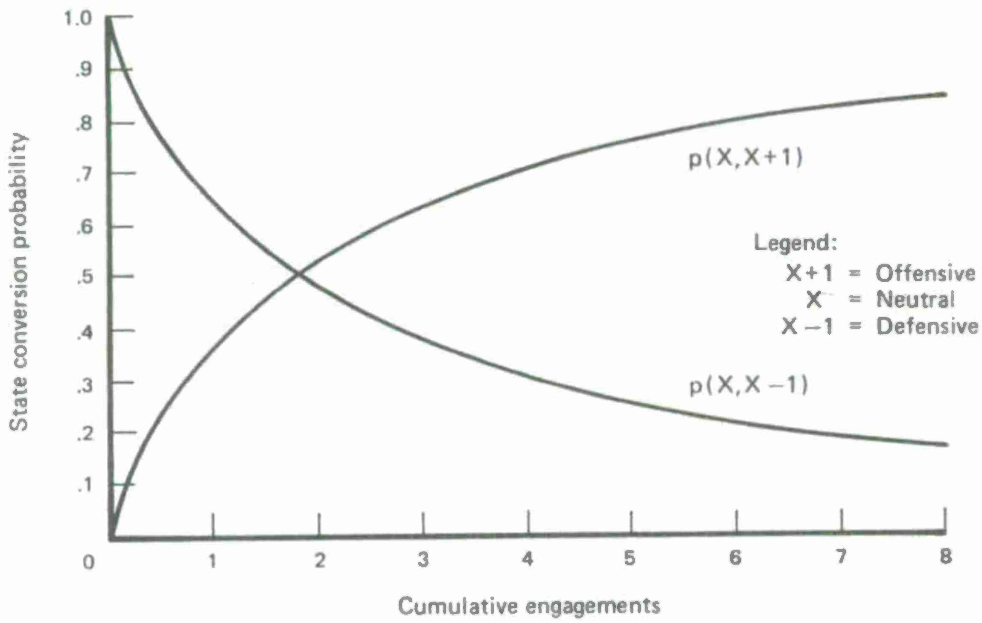

FIG. 4: REPRESENTATIVE PLOT OF ACM PERFORMANCE PARAMETERS AS A FUNCTION OF STUDENT PROGRESS

THREAT SIMULATION SELECTION

The general unavailability of threat aircraft models has hampered training fleet aircrews to engage specific threats. The procedure has been for a few aircrews -- experienced in engaging the actual threat -- to document tactics believed to counter the threat, and for fleet aircrews to practice these tactics on aircraft thought to best simulate the threat. While this is the most tolerable alternative to reproducing the threat aircraft in sufficient numbers to permit widespread training, the method lacks precision in the choice of aircraft in the inventory that best simulate the threat.

The uncertainty is further complicated by the fact that each inventory aircraft considered as a simulator can be used to simulate only a few of the known threat characteristics. Thus, while the simulation is good in some engagement areas, there may be significant deviations in others.

The ACM conversion model provides a method for quantifying the degree of simulation of the threat for each candidate inventory aircraft. In terms of the model, 2 ACM units are abstractly identical in maneuvering performance when the conversion probabilities are equal for advancement or decline from neutral state, and symmetric for conversion into/out of the other state possibilities. That is, $p(N, O) = p(N, D) = 0.5$, $p(O, OW) = p(D, FD) = p$, and $p(O, N) = p(D, N) = 1 - p$. Also necessary for combatant maneuvering equality are the relations $F(O, \cdot) = F(D, \cdot)$ and $F(OW, \cdot) = F(FD, \cdot)$. Therefore, use of the standard experiment to evaluate engagements between the threat and the candidate simulator would permit the analyst to identify areas of equivalent capability as well as significant divergence. Table 9 shows a general matrix. The same sample of expert pilots should be used for the entire experiment.